

FACTORS CONTROLLING LAVA DOME MORPHOLOGY

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Among the many spectacular venusian features revealed by Magellan, the large circular domes around Alpha Regio have generated some of the greatest interest. Early reports have suggested that, based on their shapes, such constructs may be made of high silica lavas. In order to evaluate the validity of such inferences and to better understand the factors controlling lava dome shapes, we have conducted theoretical analyses and a series of laboratory simulations designed to evaluate the role of various factors on dome aspect ratio.

The most widely used method of estimating the rheology of extra-terrestrial lava flows has been to relate the height (h) of marginal levees to their yield strength (τ_0): $\tau_0 = \rho g h \sin \theta$, where ρ = lava density, g = gravity and θ = underlying or surface slope^{1,2}. A recently published model³ has shown that the height (H) and radius (R) of sub-circular lava domes similarly can be related to the yield strength of the lava: $\tau_0 = 0.32 H^2 \rho g / R$. Both of these models were derived by balancing the gravitational stresses driving a flow forward with the yield strength holding it back, and both assume that the yield strength is a material constant of the magma, independent of its temperature. Inspection of the second of these equations shows that for a given dome diameter, height will scale as the inverse of the square root of gravity. Thus, for lava of a given yield strength, domes on the moon will tend to be about 2.5 times taller than those on earth.

Attempts to uniquely relate the yield strengths of lavas (estimated using the above equations) to composition have been largely unsuccessful^{1,2}. We suggest that it is the thickness of a lava flow's cooled carapace, rather than chemical composition, that determines the *effective* yield strength. This solidified crust that forms at the flow surface and cascades off the front to create a talus pile provides the resistance to advance commonly attributed to the lava yield strength. Thus the more rapidly crust forms, the greater the resistance to buoyant stresses, and the sooner a flow will come to rest. For a fixed eruptive volume, more rapid crust growth will lead to shorter, thicker flows and domes. Similarly, decreased gravitational stresses (as on smaller planets) will also lead to relatively stubby extrusions.

Intuitively one might assume that planetary surface temperature would play a major role in determining how rapidly a flow cools and thus what morphology will result. However, calculated cooling rates for lavas experiencing a combination of convection and radiation for likely surface conditions on all of the terrestrial planets reveal that the time scale for the flow surface to begin to solidify will be negligible relative to total emplacement times for all but the smallest extrusions. As a consequence, variations in surface temperature should not lead to significantly different dome shapes as long as the temperature does not approach the magmatic solidus.

While ambient temperature may not strongly influence the shape of domes, the *rate of extrusion* does play an important role. For a given eruptive volume, a higher extrusion rate will allow lava to flow further before surface solidification is able to stop its advance. Slower extrusion rates will result in shorter, steeper domes. Cooling is even more effective if the erupted volume comes out in a series of pulses separated by repose intervals, rather than as a single episode. The larger the number of eruptive pulses and the longer the intervening repose periods, the more effective cooling will be and the thicker the resulting extrusion. Observations of natural domes support this idea.

To begin to quantify this relationship we have conducted two sets of four experiments each in which polyethylene glycol wax was injected into a tank of cold sucrose solution. In each series, total erupted volume, repose interval, and wax properties were held constant, but the number of eruptive episodes was either 1, 2, 4, or 8. Figure 1 illustrates the results for these two series. In both cases, the aspect ratio of the dome (height/diameter= H/D) scaled linearly with the number of eruptive pulses. We are currently conducting additional experiments to evaluate how the length of the repose period affects aspect ratio. Another set of completed experiments showed that whether new magma is added to the surface (exogenous growth) or interior (endogenous growth) of a dome depends on the length of the repose period, confirming a conclusion obtained from topographic measurements of the Mount St. Helens dome⁵.

Our results thus suggest that variations in lava dome morphology on different planets will depend much more critically on local gravity and the style of eruption than on the magma composition, ambient temperature, or the relative roles of convective and radiative cooling. Eruption style in turn reflects differences in tectonic conditions and the ability of magma to exsolve volatiles. Observed crude correlations between silica content and calculated yield strengths for terrestrial lava flows and domes^{1,2} probably are due to differences in extrusion rate and volatile solubility, rather than intrinsic rheological properties. Thus, even after taking the known effect of gravity into account, observed differences in gross dome morphology on different planets cannot by themselves be directly related to composition. Additional information such as the distribution of surface textures and structures, or spectroscopic data will be needed to conclusively establish dome compositions.

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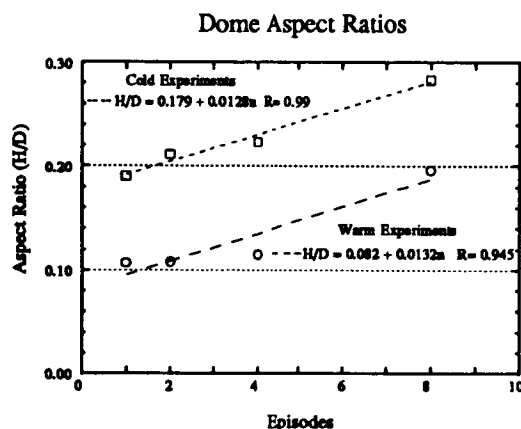


FIGURE 1. Aspect ratio as a function of number of eruptive episodes for two series of wax experiments.